Observation of the decay $\psi(2S) \to K^*(892)\overline{K} + c.c.$

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Abstract

Using 14 million $\psi(2S)$ events collected with the BESII detector, branching fractions of $\psi(2S) \to K^*(892)^+K^- + c.c.$ and $K^*(892)^0\overline{K}^0 + c.c.$ are determined to be: $B(\psi(2S) \to K^*(892)^+K^- + c.c.) = (2.9^{+1.3}_{-1.7} \pm 0.4) \times 10^{-5}$ and $B(\psi(2S) \to K^*(892)^0\overline{K}^0 + c.c.) = (13.3^{+2.4}_{-2.7} \pm 1.7) \times 10^{-5}$. The results confirm the violation of the "12% rule" for these two decay channels. A large isospin violation between the charged and neutral modes is observed.

Key words:
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1. Introduction

One of the longstanding mysteries in heavy quarkonium physics is the strong suppression of $\psi(2S)$ decays to the vector-pseudoscalar (VP) meson final states, $\rho\pi$ and $K^*(892)\overline{K} + c.c.$, referred to as the "$\rho\pi$ puzzle". In perturbative QCD (pQCD), hadronic decays of the J/ψ and $\psi(2S)$ are expected to proceed dominantly via three gluons or a single direct photon, with widths proportional to the square of the $c\bar{c}$ wave function at the origin, which is well determined from dilepton decays. Thus, it is reasonable to expect, for any hadronic final state h, the J/ψ and $\psi(2S)$ decay branching fractions should satisfy the so-called "12% rule" (1)

$$Q_h = \frac{B(\psi(2S) \to h)}{B(J/\psi \to h)} \simeq \frac{B(\psi(2S) \to e^+e^-)}{B(J/\psi \to e^+e^-)} \simeq 12\%,$$

where the leptonic branching fractions are taken from the Particle Data Group (PDG) tables (2). It was first observed by the MarkII experiment that, while this rule works reasonably well for a number of exclusive hadronic decay channels, it is severely violated for the vector-pseudoscalar meson (VP) final states, $\rho\pi$ and $K^*(892)^+K^- + c.c.$ (3). Preliminary BESI results confirm the MarkII measurements at higher sensitivity (4). This anomaly has generated much interest and led to a number of theoretical explanations (5; 6). More precise experimental results are required to distinguish between them.

In this paper, the branching fractions of charged and neutral $\psi(2S) \to K^*(892)\overline{K} + c.c.$ decays are reported, based on a sample of $14.0 \times 10^6(1 \pm 4\%)$ $\psi(2S)$ events (7) collected with the Beijing Spectrometer (BESII) (8) at the Beijing Electron-Positron Collider (BEPC).

In this analysis, a GEANT3 based Monte Carlo package (SIMBES) with detailed consideration of the detector performance (such as dead electronic chan-

nels) is used. The consistency between data and Monte Carlo has been carefully checked in many high purity physics channels, and the agreement is reasonable (9). The generator KSTARK (10), which simulates $\psi(2S) \to K^*(892)\overline{K} + c.c.$ events, together with SIMBES, is used to determine detection efficiencies.

2. Event selection

Candidate events for this decay mode have the final state $K_S^0 K^\pm \pi^\mp \to \pi^+\pi^- K^\pm \pi^\mp$. They are required to satisfy the following general selection criteria: (i) The number of charged particles must be equal to four with net charge zero. (ii) Each charged track is required to be well fitted to a three dimensional helix and be in the polar angle region $|\cos\theta| < 0.8$. (iii) Background from $\psi(2S) \to \pi^+\pi^- J/\psi$, $J/\psi \to X$ is removed by requiring that the recoil mass of any two oppositely charged tracks satisfies

$$m^{\pi\pi}_{recoil} = \sqrt{(E_{cm} - E_+ - E_-)^2 - (\vec{p}_+ + \vec{p}_-)^2} \notin (3.05, 3.15)\ \text{GeV}/c^2,$$

where $E_+(E_-)$ and $\vec{p}_+(\vec{p}_-)$ are the assumed $\pi^+(\pi^-)$ energy and momentum, respectively.

The K_S^0 is identified through the decay $K_S^0 \to \pi^+\pi^-$. The intersections of all pairs of oppositely charged tracks, assumed to be pions, are found as described in Ref. (11). The intersection is regarded as the secondary vertex. Figure 1 shows the scatter plot of the $\pi^+\pi^-$ invariant mass versus the decay length in the transverse plane (L_{xy}) for candidate events. The cluster of events with mass consistent with the nominal K_S^0 mass indicates a clear K_S^0 signal. Requirements $|m_{\pi^+\pi^-} - 0.497| < 0.018$ GeV/c^2 and $L_{xy} > 0.01$ m are used to remove background from non-K_S^0 events.

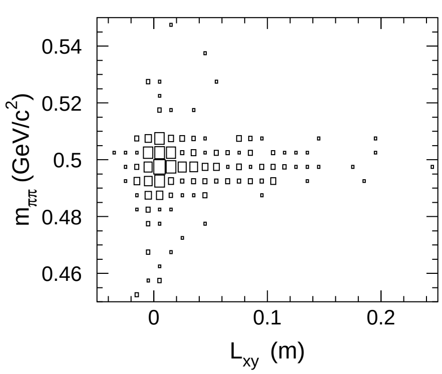

Fig. 1. The distribution of $m_{\pi\pi}$ versus L_{xy} for oppositely charged track pairs in $\pi^+\pi^- K^\pm \pi^\mp$ candidate events.

Events are kinematically fitted with four constraints (4C) to the hypothesis $\psi(2S) \to \pi_1^+\pi_2^- K^\pm \pi^\mp$. Here $\pi_1^+\pi_2^-$ are associated with the K_S^0 decay, as determined above. For the remaining two tracks, the identification as K or π is done in the following way: (i) If the momentum of one track is larger than 1.34 GeV/c, that track is assigned to be a kaon and the other track a pion. (ii) If the momenta are both less than 1.34 GeV/c, the fit is applied to the two possible combinations, and the one with the smaller χ^2 is chosen. The confidence level of the selected 4C fit is required to be larger than 0.01.

In addition, the combined chisquare (χ^2_{com}) for the assignment $\psi(2S) \to \pi^+\pi^- K^\pm \pi^\mp$ is required to be smaller than those for the alternative hypotheses $\psi(2S) \to \pi^+\pi^- K^+ K^-$ and $\psi(2S) \to 2(\pi^+\pi^-)$. Here, the combined chisquare, χ^2_{com}, is defined as the sum of the χ^2 values of the kinematic fit (χ^2_{kine}) and those from the particle identification assignments of the four tracks (χ^2_{PID}) (12): $\chi^2_{com} = \sum_i \chi^2_{PID}(i) + \chi^2_{kine}$.

After the above selection, the Dalitz plot for $K_S^0 K^\pm \pi^\mp$ candidate events, shown in Fig. 2(a), is obtained. Monte Carlo simulated $\psi(2S) \to K^*(892)\overline{K} + c.c.$ events, shown in grey-scale, lie along a horizontal band for $K^*(892)^0\overline{K}^0 + c.c.$ events and a vertical band for $K^*(892)^+K^- + c.c.$ events. Figure 2(b) shows the $K^\pm\pi^\mp$ invariant mass after an additional requirement $m_{K_S^0\pi^\pm} > 1.0$ GeV/c^2 to remove $K^*(892)^+K^- + c.c.$ events, and Fig. 2(c) shows the $K_S^0\pi^\pm$ invariant mass after an additional requirement $m_{K^\pm\pi^\mp} > 1.0$ GeV/c^2 to remove $K^*(892)^0\overline{K}^0 + c.c.$ events.

Contamination from background channels, which pass the selection criteria for the $K_S^0 K^\pm \pi^\mp$ events, mainly come from $\psi(2S) \to \gamma\chi_{cJ}$, $\chi_{cJ} \to K_S^0 K^+\pi^- + c.c.$, which are assumed to take place via the intermediate state $K^*(892)\overline{K} + c.c.$ Using the branching fractions taken from the PDG (2), the contamination from these channels is estimated to be less than 0.6 events for both the charged and neutral modes. The events along the third side of the Dalitz plot (diagonal side) in Fig. 2(a) may be due to the process $\psi(2S) \to \rho(2150)^\pm\pi^\mp$, $\rho(2150)^\pm \to K_S^0 K^\pm$. These contaminations are not corrected for, but are included in the systematic error, they and contribute an additional 5.6% systematic error for both the charged and neutral modes. The contributions from other backgrounds are negligible.

The invariant mass spectra for $K^\pm\pi^\mp$ and $K_S^0\pi^\mp$ are fitted using the $K^*(892)$ signal shape determined

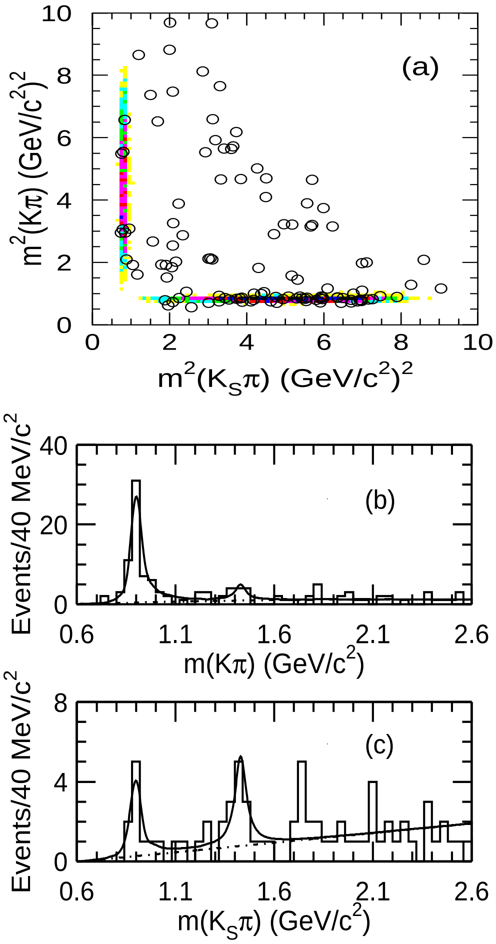

Fig. 2. (a) Dalitz plot, (b) $K^\pm\pi^\mp$ invariant mass, and (c) $K^0_S\pi^\pm$ invariant mass for $K^0_S K^\pm\pi^\mp$ candidate events after the selection described in the text. The circles are data, and the shaded regions are simulated $\psi(2S) \to K^*(892)\overline{K} + c.c.$ events (the horizontal band for $K^*(892)^0\overline{K}^0 + c.c.$ and the vertical band for $K^*(892)^+K^- + c.c.$). The curves in (b) and (c) show the fit described in the text.

with MC simulation plus a second order polynomial background and an additional Breit-Wigner function for the $K^*_J(1430)$ (described below), as shown in Figs. 2(b) and (c); 65.6 ± 9.0 $K^*(892)^0\overline{K}^0 + c.c.$ and 9.6 ± 4.2 $K^*(892)^+K^- + c.c.$ events are observed. Their detection efficiencies are $(9.68 \pm 0.07)\%$ and $(7.25 \pm 0.07)\%$, and their statistical significances are 11σ and 3.5σ, respectively.

In addition, 10.5 ± 5.1 events and 11.2 ± 5.3 events near 1430 MeV are found in the invariant mass spectra of $K^\pm\pi^\mp$ and $K^0_S\pi^\pm$, respectively, by fitting with Breit-Wigner functions with the means fixed at 1.43 GeV/c^2. Their fitted widths are roughly 46 MeV/c^2 and 100 MeV/c^2, and corresponding statistical significances are 3.4σ and 3.1σ, respectively. These events might be associated with the $K^*_0(1430)$, $K^*(1410)$ or $K^*_2(1430)$, but the limited statistics does not allow a determination of the spin J (=0, 1, or 2). Their detection efficiencies are $(9.2 \pm 1.0)\%$ and $(7.7 \pm 0.9)\%$, where the errors reflect the unknown spin.

3. Systematic errors and contributions from continuum

The branching fraction is calculated from

$$B = \frac{n^{obs}}{N_{\psi(2S)} \cdot B_{int} \cdot \epsilon \cdot f_c},$$

where n^{obs} is the number of observed $K^*(892)\overline{K} + c.c.$ events, ϵ is the detection efficiency obtained from the MC simulation, $f_c = (96.3 \pm 3.3)\%$ is an efficiency correction factor from the K_S reconstruction (11), $N_{\psi(2S)}$ is the total number of $\psi(2S)$ events, and $B_{int} = 1/3$ is taken as the branching fraction for $K^*(892)\overline{K} + c.c. \to K_S K^\pm\pi^\mp$. The $K_S \to \pi^+\pi^-$ branching ratio was included in the Monte Carlo simulation.

Many sources of systematic error are considered. Those associated with the efficiency are determined by comparing J/ψ and $\psi(2S)$ data with Monte Carlo simulations for very clean decay channels, such as $J/\psi \to \rho\pi$, $K^*(892)\overline{K} + c.c.$, and $\psi(2S) \to \pi^+\pi^- J/\psi$, which allow the determination of systematic errors associated with the MDC tracking efficiency, kinematic fitting, particle identification, photon selection efficiency and other experimental effects (13). The uncertainties of the background shapes and the total number of $\psi(2S)$ events are also sources of systematic errors. The total systematic errors for charged and neutral $K^*(892)\overline{K} + c.c.$ mode are 14.0% and 12.6%, respectively. Table 1 summarizes the systematic errors.

Contributions from the continuum $e^+e^- \to \gamma^* \to$ hadrons (14; 15) are estimated using a sample taken at $\sqrt{s} = 3.65$ GeV of 6.42 ± 0.24 pb^{-1} (16), about one-third of the integrated luminosity at the $\psi(2S)$. In $K^*(892)^0\overline{K}^0 + c.c.$, $2.5^{+2.6}_{-1.8}$ events are observed, as shown in Fig. 3, while no events are observed in the $K^*(892)^+K^- + c.c.$ channel, which corresponds to $0.0^{+1.3}_{-0.0}$ events at the 68.3% confidence level (17).

4. Results

Table 2 summarizes the observed numbers of events, detection efficiencies, and corresponding cross sections for $K^*(892)\overline{K} + c.c.$ channels at $\sqrt{s} = 3.65$ GeV and $m_{\psi(2S)}$, respectively. Here, detection efficiencies at $\sqrt{s} = 3.65$ GeV include the effect of

Table 1

Summary of systematic errors (%).

	$K^*(892)^{\pm}K^{\mp}$	$K^*(892)^0\overline{K}^0 + c.c.$
Tracking	8.0	8.0
kine. fit	2.9	2.9
Bkgd shape	5.0	5.1
Bkgd comtam.	8.4	5.7
K^0_S reconstion	3.4	3.4
MC statistics	1.1	1.0
$N_{\psi(2S)}$	4.0	
sum	14.0	12.6

initial state radiation. In addition, the cross sections of $e^+e^- \to K^*_J(1430)^0K^0 + c.c. \to K^0_SK^{\pm}\pi^{\mp}$ and $e^+e^- \to K^*_J(1430)^+K^- + c.c. \to K^0_SK^{\pm}\pi^{\mp}$ at 3.686 GeV are determined to be $6.0 \pm 2.9 \pm 1.0$ pb and $7.7 \pm 3.6 \pm 1.3$ pb, respectively, where the first errors are statistical and the second systematic, including the uncertainty from the unknown spin. The corresponding upper limits are 11.4 pb and 13.7 pb, respectively, at the 90% confidence level.

Table 3 lists the branching fractions for the

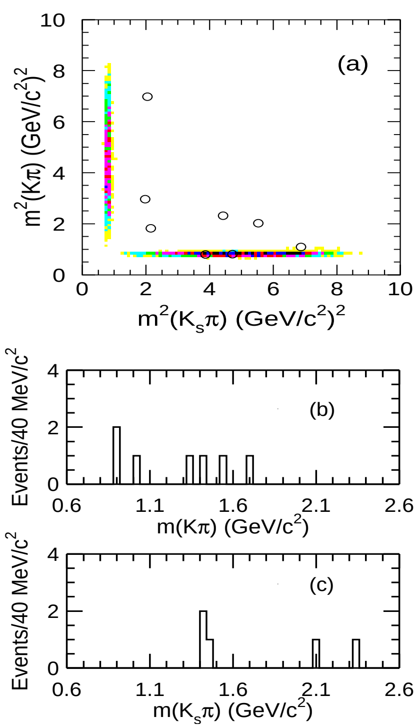

Fig. 3. (a) Dalitz plot, (b) $K^{\pm}\pi^{\mp}$ invariant mass, and (c) $K^0_S\pi^{\pm}$ invariant mass for $K^0_SK^{\pm}\pi^{\mp}$ candidate events in the $\sqrt{s} = 3.65$ GeV data sample. The circles are data, and the shaded regions are simulated $\psi(2S) \to K^*(892)\overline{K} + c.c.$ events (the horizontal band for $K^*(892)^0\overline{K}^0 + c.c.$ events and the vertical band for $K^*(892)^+K^- + c.c.$ events).

Table 2

Observed cross sections for $e^+e^- \to K^*(892)\overline{K} + c.c.$ at $\sqrt{s} =$ 3.65 GeV and 3.686 GeV.

Channels	$\sqrt{s}$ (GeV)	N^{obs}	ϵ (%)	σ (pb)
$K^*(892)^+K^- + c.c.$		$0.0^{+1.3}_{-0.0}$	5.7	< 21 (90% C.L.)
$K^*(892)^0\overline{K}^0 + c.c.$	3.65	$2.5^{+2.6}_{-1.8}$	7.7	$16^{+16}_{-11} \pm 2$
				< 42 (90% C.L.)
$K^*(892)^+K^- + c.c.$	3.686	9.6 ± 4.2	7.3	$20.9 \pm 9.1 \pm 2.9$
$K^*(892)^0\overline{K}^0 + c.c.$		65.6 ± 9.0	9.7	$107 \pm 15 \pm 13$

Table 3

Branching fractions measured for $\psi(2S) \to K^*(892)\overline{K} + c.c.$. The corresponding J/ψ branching fractions (2) and the ratios $Q_h = \frac{B(\psi(2S))}{B(J/\psi)}$ are also given.

Channels	$B(\psi(2S))$ ($\times 10^{-5}$)	$B(J/\psi)$ ($\times 10^{-4}$)	Q_h (%)
$K^*(892)^+K^- + c.c.$	$2.9^{+1.3}_{-1.7} \pm 0.4$	50 ± 4	$0.59^{+0.27}_{-0.36}$
$K^*(892)^0\overline{K}^0 + c.c.$	$13.3^{+2.4}_{-2.8} \pm 1.7$	42 ± 4	3.2 ± 0.8

$\psi(2S) \to K^*(892)\overline{K} + c.c.$ decay modes, where the contributions of the continuum is subtracted incoherently with normalized integrated luminosity without considering its interference with the resonant amplitude. The table also lists the branching fractions of J/ψ decays (2) as well as the ratios of the $\psi(2S)$ to J/ψ branching fractions. The ratio $\frac{B(\psi(2S)\to K^*(892)^0\overline{K}^0+c.c.)}{B(\psi(2S)\to K^*(892)^+K^-+c.c.)} = 4.6^{+2.9}_{-2.2}$ shows a large isospin violation between the charged and neutral modes of $\psi(2S) \to K^*(892)\overline{K} + c.c.$ decays. Since the amplitudes for $\psi(2S) \to K^*(892)\overline{K} + c.c.$ decays up to first order in the SU(3) breaking consists of two parts: the strong decay amplitude and the electromagnetic amplitude (18), a possible interpretation for this large isospin violation is that the electromagnetic decay amplitude plays an important role in $\psi(2S) \to K^*(892)\overline{K} + c.c.$ decays, while in J/ψ decays the strong decay amplitude dominates. The results listed in Table 3 show that, $\psi(2S) \to K^*(892)\overline{K} + c.c.$ branching fractions are strongly suppressed with respect to the pQCD expectation. The charged branching fraction is suppressed more than the neutral one and is consistent with the upper limit measured by the MarkII experiment ($< 5.4 \times 10^{-5}$, at 90% C.L.) (3). Our results marginally accommodate the predictions by Chaichian et al. and by Feldmann et al. (5), two predictions for the charged mode branching fractions are 4.5×10^{-5} and 1.2×10^{-5} respectively, while being larger than their two predictions for the neutral mode

(7.6×10^{-5} and 5.1×10^{-5}, respectively). Ma (5) predicted Q_{K^*K} to be $(3.6\pm0.6)\%$, which is consistent with our measurement for the neutral mode, but not for the charged mode.

Based on the observed cross sections in Table 2, the branching fractions of $\psi(2S)\to K^*(892)^+K^- + c.c.$ and $K^*(892)^0\overline{K}^0 + c.c.$ may be calculated by the model proposed in Ref. (15), where all the contributions from the continuum one-photon annihilation amplitude, the electromagnetic amplitude and the three-gluon amplitude of the $\psi(2S)$ decay, and their interferences are taken into account. By fitting these observed cross sections the phase between the electromagnetic amplitude and three-gluon amplitude of the $\psi(2S)$ decay is constrained in the range from 95^0 to 304^0, disfavors the positive solution of the orthogonal phase $\pm90^0$ determined from J/ψ decays (6). The branching fractions in this case are: $B(\psi(2S)\to K^*(892)^+K^- + c.c.) = (3.1^{+1.8}_{-1.9})\times10^{-5}$ and $B(\psi(2S)\to K^*(892)^0\overline{K}^0 + c.c.) = (13.7^{+1.8}_{-9.0})\times10^{-5}$, where the large errors are due to the large phase uncertainty.

In conclusion, we present the branching fractions for $\psi(2S)\to K^*(892)^0\overline{K}^0 + c.c.$ and $K^*(892)^+K^- + c.c.$. They are suppressed with respect to the pQCD expectation, and a large isospin violation between the charged and neutral mode is observed. These results are compatible with those recently reported by CLEO Collaboration for the same channels in ref. (19).

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